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STREAMS: a new method for analysing material flows through society

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Abstract

For the development of material, product and waste oriented policies, knowledge about the flow, use and disposal of materials through society is necessary. The risks of taking policy measures leading to suboptimum solutions of environmental problems call for an integral survey of material flows through society. However, up to now, integral analyses of physical material flows have been lacking. Problems such as differences in definitions, in subdivisions of flows and in reference years make it difficult to relate data from different sources to obtain an overall view. In this article, STREAMS, a new method to calculate physical material flows through society, is proposed. The method is based on the so-called supply and use tables, which describe a country's economy in terms of supply and use of materials, products and services by industries, service sectors and consumers. In our approach, materials and products are tracked on their way from extraction of raw materials to the final consumption of products and beyond, into the stage of waste. The method has the advantage of deriving almost all data from one source. In this article the method is described. In a separate study, the method is applied to obtain an integral survey of the flow of plastics through The Netherlands, showing that the method can be used to assess the final materials consumption on a highly detailed level. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Traditionally, materials use is summarised as extraction of raw materials from the environment, using them for a certain purpose and finally discarding and returning them to the environment in the form of waste. Because of the growth of the earth's population, the need to improve the standard of living in developing countries and the overall increase of consumption, there is a growing demand for raw materials. As a result, various problems become obvious—e.g. the exhaustion of limited resources, the emission of pollutants to the environment and the production and disposal of waste. Materials are used to deliver services to fulfil a variety of human needs. For a sustainable use of resources it is essential to use these materials more efficiently; this can be achieved by decreasing the amount of materials needed per unit of service or extending the period in which materials are being used. In the past, much effort was put into 'end-of-pipe' measures, such as separation and incineration of wastes. Nowadays it has become more apparent that these measures are not sufficient to ensure the sustainability of materials use. For that purpose, attention should also be given to product design (design for recycling), the selection of materials and the design of manufacturing processes.

To be able to improve the efficiency of raw materials use, knowledge about the flow of these materials through society, at all stages of their lifetime—'from cradle to grave'—is a prerequisite. Therefore, an integral analysis of these material flows is needed. However, reliable data for this analysis are generally very hard to be found. In a previous analysis of the potential of material efficiency improvement in the use of packaging [1], it was found that comprehensive data on disaggregated levels about the use of materials in various functions and products was lacking. In the literature, assessments of material flows through society mostly concern specific stages in the lifetime of materials: most studies focus either on production figures or on waste figures. In trying to relate these assessments to get an overall picture, the problem arises that every author, often implicitly, uses his own approaches, definitions, reference years and subdivisions of material flows. Given these problems, it is concluded that a new approach is needed to allow integrated mapping of material flows through society.

From an environmentalist's point of view the most interesting issue, when mapping the amount of materials circulating in society, is the input of raw materials that is needed to keep the system going. National statistics about the use of materials can provide an impression of this input. However, because of imports and exports, the use of raw materials in a country does not say much about the amount of raw materials that is finally consumed in that country. In this study we are especially interested in the amount of materials that enter the stage of final consumption. The stage of final consumption is the essential phase in the life of products, as in this stage they provide the services they were produced for. The demand for services, together with the material intensity per unit of service, can be seen as the engine that drives the system of material flows through society. After final consumption the products turn into waste. The materials contained in the waste, however, may be recycled and used to produce other products.

Unfortunately, there is an almost complete lack of direct information about the final consumption of products. Frequently a country's apparent consumption of a certain product, calculated as production plus imports minus exports, is used as an estimate for its final consumption. However, this estimate only holds for final products, which are not processed further and which are not used as packaging or as component. Rather, for materials and intermediate products, apparent consumption means 'the use in industry'. They change hands one or more times before reaching the final consumer, so, in this case the apparent consumption is not a very good estimate of the final consumption. Apart from that, imports and exports of packaging and components, together with the goods they are applied to, are invisible in statistics, so they can not be tracked directly.

Given all these problems and limitations, we developed a new method to map and quantify the material flows through society on a disaggregated level. In this article, this method, called STREAMS (STatistical REsearch for Analysing Material Streams), is presented. The method is based on the use of economic statistical data. Within STREAMS, much attention is paid to the assessment of the final consumption of packaging and components.

In Section 2 the STREAMS method is described in detail. In Section 3 some methodological aspects are discussed. In Section 4, conclusions are drawn about the abilities of the method, partly based the results of case studies which are published in separate articles [2,3]. Finally, recommendations are made for further refinement and testing of the method.

2. Methodology

In this section, the STREAMS method is described. The method is based on the use of economic supply and use tables, which provide an overview of a country's material flows in monetary terms. These tables are compiled annually by the national statistical offices of a number of countries, including The Netherlands and Germany. The tables present a total description of the economy of a country in terms of the supply and use of goods and services by industries as well as consumers. Also, figures about imports and exports are included. Although the level of detail of these tables varies considerably between countries, they contain a lot of information that can be used to analyse the flow of materials through society.

Before proceeding, some definitions have to be made clear. We use the term 'materials' to indicate substances that have no clearly defined form. Examples are ores, oil, plastic granulate, etc. Objects that have a defined form (tangible objects) are called 'products'. Note that we use a narrow definition of the term 'products': in our terminology, materials and services are not called 'products', although they are 'produced' by certain industries or service sectors. 'Materials' and 'products' together are called 'goods' or 'commodities'. The delivery of 'goods' or 'commodities' involves substance flows, in contrast to the delivery of 'services', for which the accompanying substance flows are negligible.

In Section 2.1, we present a schematic representation of material flows through society. In Section 2.2 and Section 2.3 the STREAMS method is described in detail. The method consists of two parts. In Section 2.2 we describe the first part, the 'supply and use analysis', in which the main material flows are mapped relatively straightforwardly from the supply and use tables. The analysis results in data on the supply and the direct use (apparent consumption) of goods. The second part, the 'final consumption analysis', which is described in Section 2.3, consists of a calculation method for the final consumption of products.

2.1. Schematic representation of material flows through society

In the STREAMS method material flows through society are modelled as shown in Fig. 1. In this figure material flows are represented as arrows between boxes. Boxes represent processes. Each flow can be composed of several subflows, representing various (sub-)types of materials or products. Each process can be broken down into various types of processes or into various industries by which the process is conducted.

The main direction of the material flows in Fig. 1 is from the top to the bottom. On this route materials pass through several phases of their life-cycle. They enter as raw materials, in the form in which they were extracted from the environment. In the first operation, the materials production operation, they are converted into intermediate materials. Intermediate materials are, for example, primary plastics for injection moulding, or pulp for paper production. In the materials processing operation the intermediate materials are processed into products. Three types of products are discerned: packaging, components and final products.

Final products are already suitable for final consumption: they need no further processing step. Packaging and components are intermediate products: they need a packing or assembly operation respectively before reaching their final consumers. The industries that use packaging to pack their products and the industries that use components to assemble them to their goods are not the final consumers of those packaging and components. In contrast, the (final) consumers (e.g. households, industries and exports) of the goods they produce are also the final consumers of the packaging and components, which come along with those goods. There the packaging and components eventually become waste.

Final consumers discard products in the form of post-consumer waste. The materials production, materials processing, packing and assembly operations described above bring about production, processing, packaging and assembly wastes, which, added to the post-consumer waste, form the total waste volume. A part of the total waste is recycled. The rest, defined as final waste, has to be incinerated or landfilled. The recyclable part can either be used as secondary raw material for materials production or as secondary intermediate material for materi-

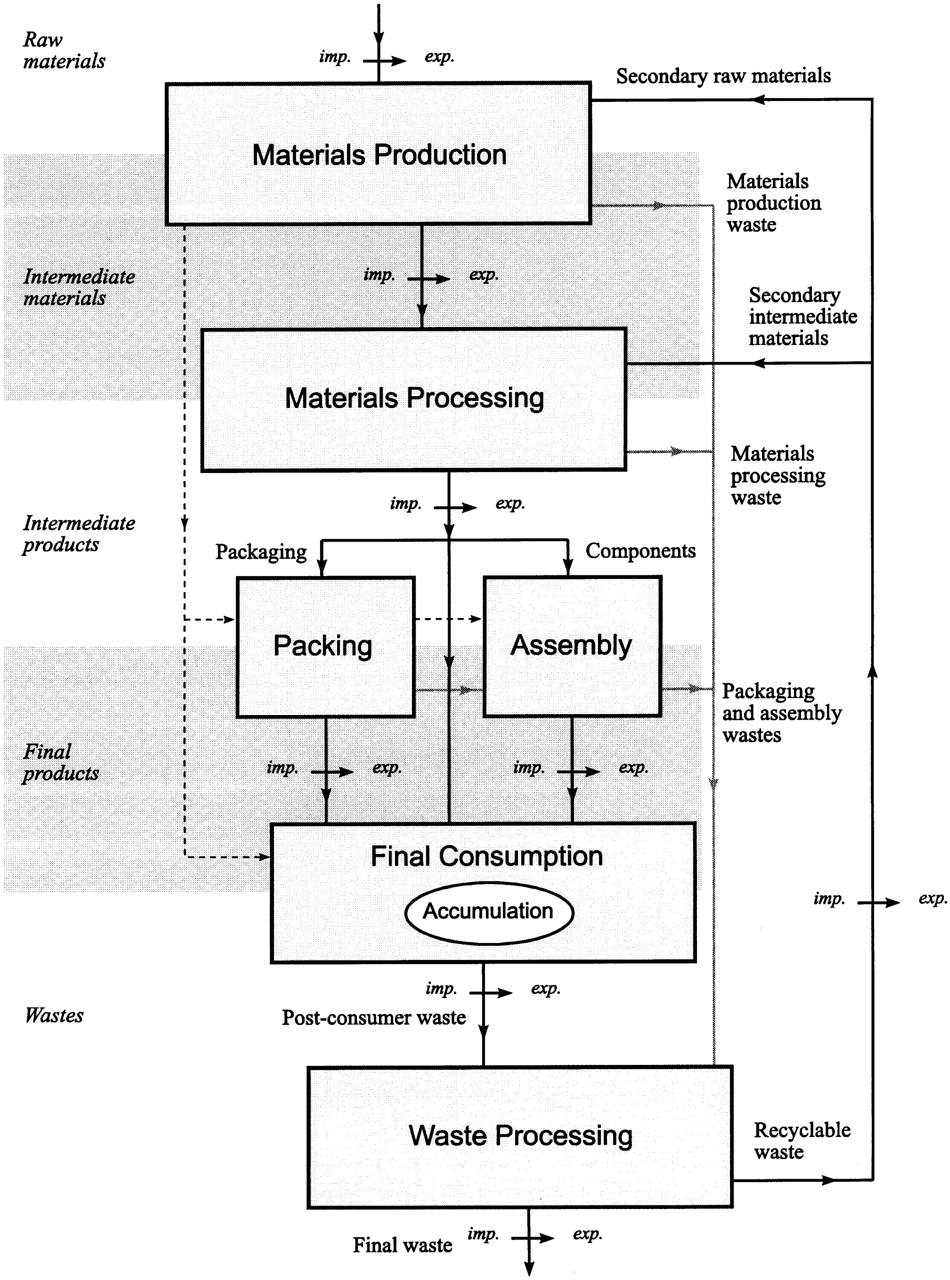

Fig. 1. Schematic representation of material flows through society.

als processing, depending on the material and the recycling route followed[1].

Usually, materials flows research is conducted for a specific material or group of materials (e.g. plastics, wood or steel). In this article, these materials are called core materials. Products that mainly consist of core materials are called core products. In this article, the main industries that produce or process core materials or core products are called core industries to distinguish them from the other materials, products and industries in the economy.

To use Fig. 1 to map specific material flows in a specific year, stocks have to be taken into account. The largest stock exists in the stage of final consumption, representing the materials that are currently in use in the form of final products. Because the final consumption is subject to changes in time, the stock of materials in society changes too. In Fig. 1 this stock is modelled as an accumulation process. In fact, stocks exist between all processing steps. However, in our approach, apart from the stock at the stage of final consumption, stocks are neglected, because they are relatively small and stable compared to the annual flow of materials[2].The result of this assumption is that the total input of a process equals the total output (including waste), which would not be the case if stocks were included.

To use the model to map specific material flows in a specific year in a specific country, imports and exports of core raw materials, intermediate materials, packaging, components, final products and wastes have to be taken into account, as well as (indirect) imports and exports of packaging around goods and components within all kinds of products.

So far, we have spoken about material flows between processes. However, in statistics industries are discerned instead of processes. In some cases several processes take place successively in one single industry. In that case processes do not become visible in statistics separately. For this reason virtual flows were added to Fig. 1, indicated by dotted lines, apparently by-passing the materials processing, packing and assembly processes.

2.2. The supply and use analysis

In this section we describe the supply and use analysis to map specific material flows in a specific country in a specific year using the country's supply and use tables. As an example the supply and use tables for The Netherlands are schematically shown in Fig. 2 [4]. Depending on the aggregation level, in the supply and use tables a number of goods, services, industries, service sectors and final demand categories[3] are discerned. All figures are expressed in monetary units. Only commercial deliveries are mapped, so most of the waste flows are invisible, simply because they are not traded.

[1] Multiple use of packaging and components and reuse of final ('second-hand') products are not discerned. In Fig. 1 they stay in the final consumption stage until they are finally discarded.

[2] The use table contains a column 'stock mutation', which gives an indication of the relative importance of changes in stocks. From the use table of The Netherlands it can be concluded that for almost all products stock mutations are well beneath 5% of total use.

[3] Mainly households.

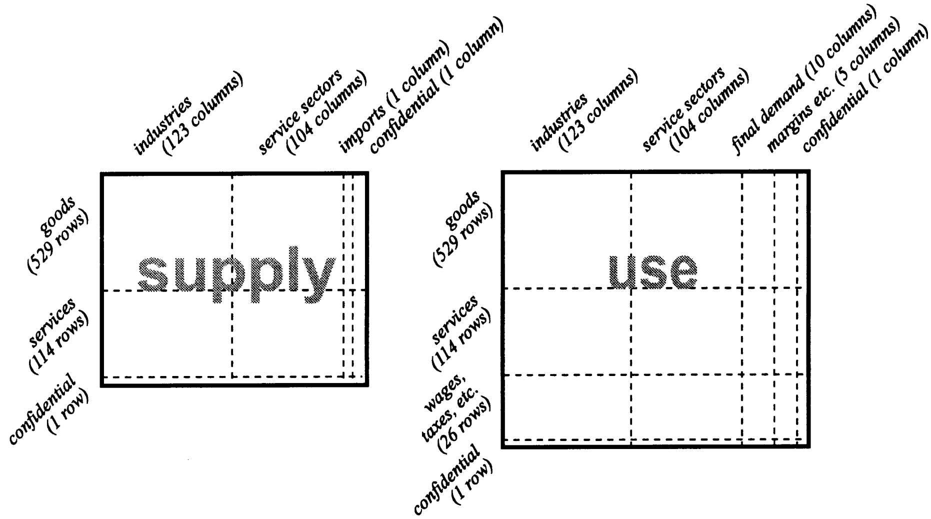

Fig. 2. Outline the supply and use tables for The Netherlands as issued annually by Statistics Netherlands [5].

In the STREAMS method, physical data on the supply and direct use (apparent consumption) of core materials and products are obtained in several successive steps, which will be described below. First, a process scheme of the material under investigation is constructed and core materials, core products and core industries are discerned (1). Next, core supply and use tables are assembled from the total supply and use tables (2). These monetary tables are corrected for confidential trade (3) and converted into physical units (4). Subsequently, the tables are corrected for intrasectoral trade (5). Eventually, after calculation of the core materials contents of core products (6), physical data on the supply and direct use (apparent consumption) of core materials can be derived.

1. **Construction of the process scheme and assignment of core materials, core products and core industries**. A process scheme of the material under investigation is constructed to get an overview of the material flows and processes involved, using Fig. 1 as a guideline. Core raw materials, core intermediate materials and core products are discerned. Also core materials production industries and core materials processing industries are discerned.
2. **Construction of core supply and use tables**. Core supply and use tables ($\mathbf{S_c}$ and $\mathbf{U_c}$) are constructed by extracting those rows from the supply and use tables $\mathbf{S}$ and $\mathbf{U}$ which represent the flows of the core materials and products in a specific year (in monetary terms).
3. **Correction for confidential supplies**. As can be seen from Fig. 2, some data on supplies and uses are kept confidential. In the supply and use tables these are collected in the column 'confidential'. Statistics offices are obliged to keep some data out of publications if the material or product under investigation is manufactured by only a few companies who do not want to see their turnovers

published. If the core supply and use tables contain confidential supplies and uses, assumptions have to be made about the 'confidential' users and suppliers of core materials and products. For these assumptions, the row 'confidential' in the supply and use tables, showing the total confidential supplies and uses per industry, provides additional indications. With these assumptions, the core supply and use tables are corrected to represent the 'true' supplies and uses.

4. **Conversion of monetary data into physical data**. A conversion of monetary data into physical data is needed to allow a physical analysis of material flows. This conversion can be done several ways. The highest accuracy is achieved if for all core materials and products mean prices per unit are used for each individual industry. However, in many cases, price information on this detailed level is not available. In some cases in the national statistics—e.g. the statistics of foreign trade[4] or production statistics—average retail prices[5] can be found which are averages for the total national supplies of the core materials and products. If no such statistics are available, other data sources (e.g. market inquiries) have to be used to obtain mean prices of the core materials and products. In general, however, this will lead to less accurate results. By dividing the core supply and use tables $\mathbf{S_c}$ and $\mathbf{U_c}$ by the mean prices of the core materials and products, physical core supply and use tables $\mathbf{S_c^*}$ and $\mathbf{U_c^*}$[6] are obtained.
5. **Correction for intrasectoral trade**. A correction for intrasectoral trade has to be made to the core supply and use tables $\mathbf{S_c}$ and $\mathbf{U_c}$. Companies may buy a certain amount of their input and output core materials and products from colleagues within the same industry. These core materials and products appear in the supply and use tables both as supplies and as uses of the same industry. To correct for this, in the STREAMS method, for each industry the net use and the net supply of core materials and products are calculated.
6. **Calculation of the core materials content of core products**. In general, core products do not entirely consist of core intermediate materials. They may contain all kinds of additives and they may be composed of several components, some of which are not made of core intermediate materials. This implies that the weight of core products is not directly a measure for the use of core materials. By analysing the mass flows of the core material processing industries, it is possible to calculate the percentage of core intermediate materials in core products. In our approach this is done by comparing the outputs of core products with the inputs of core intermediate materials, taking into account the amount of core materials processing waste produced. Using this percentage, the

[4] In that case, the assumption is made that mean expoert prices match with mean domestic selling prices.

[5] Because of value added by trade and transportation, purchase prices are not equal to retail prices. Purchase prices can be calculated from retail prices taking into acount this value added, which can be found in a separate column in the (core) supply and use tables.

[6] Tables indicated with an asterisk (*) are expressed in physical units (kg or ktonnes); tables without an asterisk are expressed in monetary units.

supplies and uses of core products in the core supply and use tables are converted into their core intermediate materials content. Therefore, in our method, all weight figures for core products concern their intermediate materials content. For some materials it may also be possible to calculate the core raw materials content. This depends on the availability of data on the supply and use of the core raw materials in the supply and use tables. In these cases the core raw materials content of core intermediate materials can be obtained by conducting a mass flow analysis of the core materials production industries. The core raw materials content of core products can be obtained by subsequently conducting a mass flow analysis of the core materials processing industries, as described above.

If the core supply and use tables are sufficiently detailed, it is possible to read from the physical core supply and use tables:

- the use of core raw materials;
- the supply of core intermediate materials;
- imports and exports of core intermediate materials;
- the use of core intermediate materials by the core materials processing industries;
- the use of core intermediate materials by other industries and consumers;
- the supply of core products (packaging, components and final products) by the core materials processing industries;
- the supply of core products by other industries;
- imports and exports of core products;
- the use of core products by industries, service sectors and households;
- the supply and use of core waste materials (as far as they are traded).

With the results obtained so far, physical amounts can be added to the material flows in Fig. 1, as far as the 'materials production' and 'materials processing' stages are concerned.

2.3. The final consumption analysis

Above, only direct supplies and purchases were determined: supplies and purchases that can be read directly from the physical core supply and use tables. However, the direct purchases of packaging and components, as found in the core use table, do not specify their final consumption, because the industries that purchase them are not the final consumers. Packaging and components are used indirectly: they change hands once more before reaching their final consumer. In the STREAMS method packaging and components are assigned to their final consumers in the final consumption analysis, which is described in this section.

The essence of the final consumption analysis is schematically represented in Fig. 3. Each industry has its specific uses and supplies of materials and products. All materials and products that are used are bought with the aim of producing the materials and products to be supplied. Part of the materials and products that are used leave the industry together with the goods supplied, either as component or as packaging. The other part of the materials and products is used as final product. After final consumption they leave the industry in the form of waste. This description of material flows inside industries applies to all products that are used. However, for our analysis only the use of core materials and products is of importance. In our approach, for each industry the purpose of the input of core materials and products is estimated and divided between packaging, components and final products. This estimate is based on the industry's supply of goods and general knowledge on packaging practices and product compositions. Subsequently, packaging and components are allocated to the supply of materials and products of that industry. Finally, the packaging and components are allocated to the users of those materials and products.

The successive steps of the method, which are described below, are displayed in Fig. 4. In this figure a three-dimensional representation is used, which is explained by the definition block in the upper part of Fig. 4. The industries, service sectors and final demand categories are depicted along the x-axis, all goods (all of the goods discerned in the supply and use tables) along the y-axis and the core materials and products along the z-axis. In this space, planes represent tables.

The calculation method for the final consumption of core materials and products consists of the following successive steps:

1. Evaluation of the purpose of use of core materials and products. To distinguish the different purposes of use, the physical core use table $\mathbf{U}_{\mathbf{c}}^{*}$, containing the use of core materials and products, is split up into several new physical core use tables. The first one is $\mathbf{U}_{\mathbf{cp}}^{*}$, indicating the use of core materials and products to be used as packaging[7]. The second one is $\mathbf{U}_{\mathbf{cc}}^{*}$, indicating the use of core materials and products to be used as component. The third one is $\mathbf{U}_{\mathbf{cf}}^{*}$, indicating the use of core materials and products to be used as final product. Core

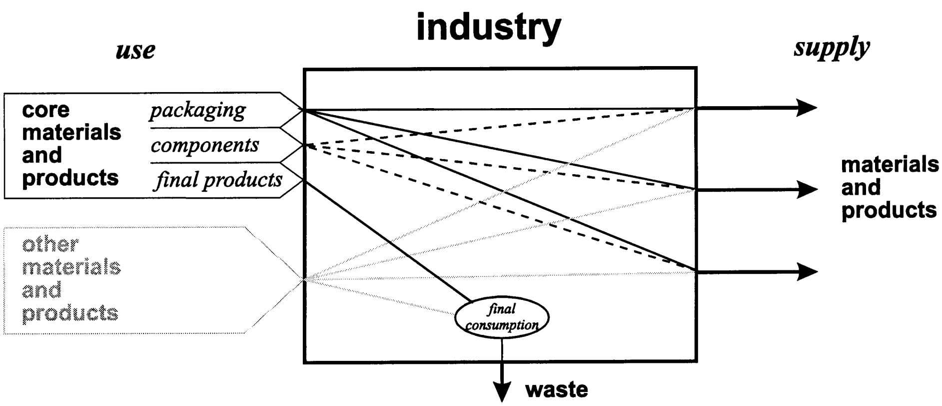

Fig. 3. Schematic representation of the allocation of the use of core materials and products by an industry to its supplied goods.

[7] Durable packaging which eventually returns to the industry that has bought it and that finally discards it are excluded. The decision whether a use of packaging must be seen as final consumption (Table $\mathbf{U}_{\mathbf{cf}}^{*}$) or as intermediate product (Table $\mathbf{U}_{\mathbf{cp}}^{*}$) is the consideration whether the packaging is finally discarded by the using industry or by the consumer of the goods produced by that industry.

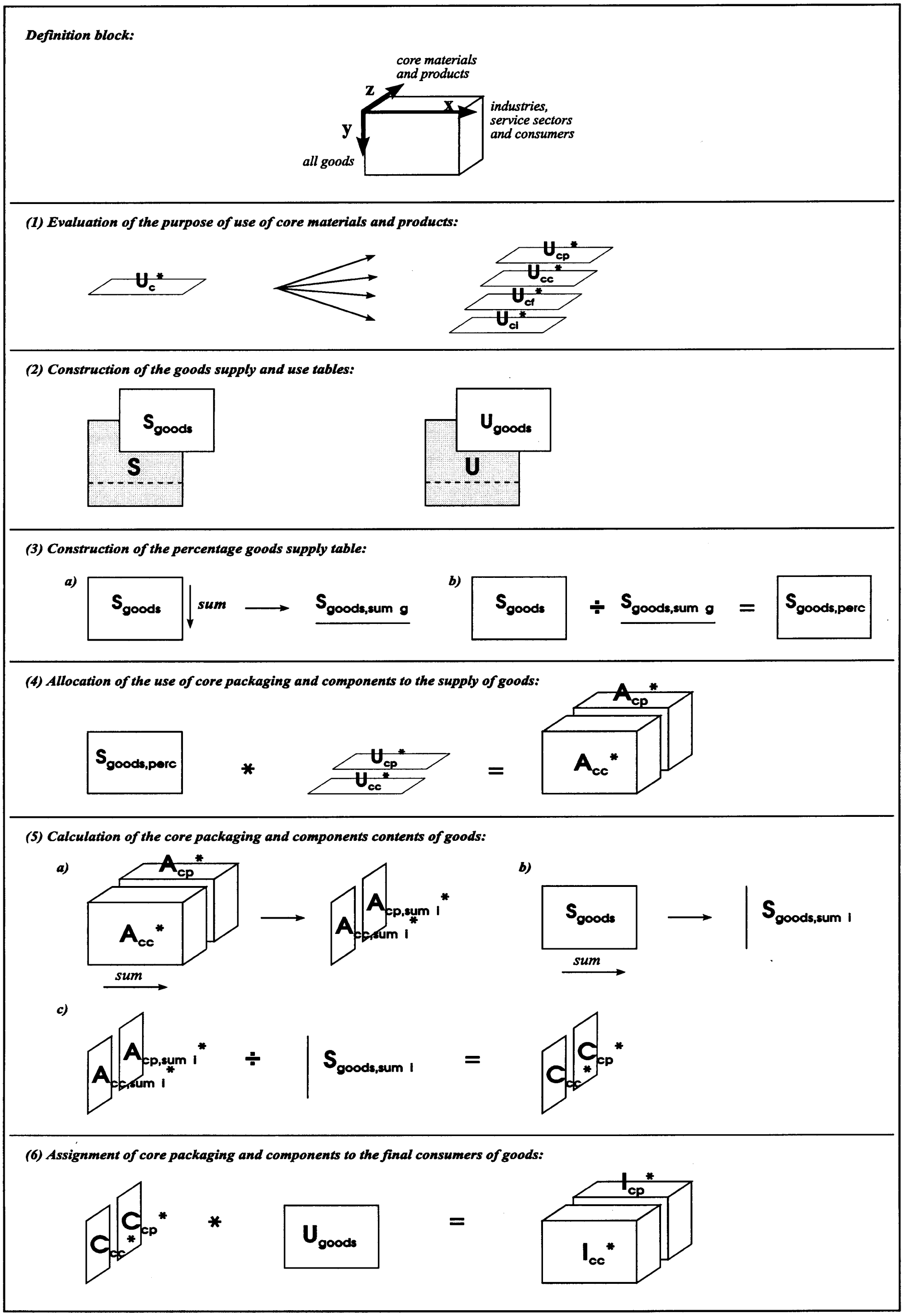

Fig. 4. Method to calculate the final consumption of core materials and products. The method consists of six successive steps, as indicated in the figure. Representation in three-dimensional space: x-axis, industries; y-axis, all goods; z-axis, core materials and products. An explanation of the abbreviations can be found in the main text.

intermediate materials are processed into core products (see Fig. 1), which can be used as packaging, as component or as final product. So in principle it should be sufficient to estimate the purpose of use of core products only. However, if the materials processing operation is carried out by the same industry as the packing, assembling or final consuming industry, these core intermediate materials seem to be used as packaging, component or final product directly, because they appear in the use table only in the form of intermediate materials. In Fig. 1 these uses are indicated by dotted lines. In order to make it possible to assign these intermediate materials to the goods they are applied to (as packaging or as component), the purpose of their use (packaging, component or final product) is also evaluated. If core intermediate materials are used as packaging, component or final product by another industry than the materials processing industry, they appear twice in the core use table: once as intermediate material and once as intermediate or final product (see Fig. 1). If both were used in the calculations, this would lead to double counting. In order to avoid this, core intermediate materials to be used for producing core products should be left out of the calculations. In our approach these are collected in a fourth physical core use table, $\mathbf{U}^*_{\mathbf{ci}}$, which is not used in further calculations. The evaluation of the purpose of use can be executed in several ways. The descriptions of some core materials and products in the use table already indicate what purpose they are used for. 'Plastic packaging', 'metal machine parts' and 'wooden furniture' will generally be used for one purpose only, namely as packaging, component and final product, respectively. In this case the rows of $\mathbf{U}^*_{\mathbf{c}}$ representing the use of those core materials and products can be moved to $\mathbf{U}^*_{\mathbf{cp}}$, $\mathbf{U}^*_{\mathbf{cc}}$ or $\mathbf{U}^*_{\mathbf{cf}}$ entirely (each using industry uses them for the same purpose). Other core materials and products, however, are used for several purposes. Plastic films, for example, are either used as packaging, or as component (upholstery), or as final product (agricultural films). For these core materials and products the purpose depends on the user and on the goods he produces. In that case an estimate of the purpose of use of the core material or product per industry is made, based on the industry's supply of goods and general knowledge on packaging practices and product compositions. As a result, figures from $\mathbf{U}^*_{\mathbf{c}}$, representing the use of those core materials and products by specific industries, are moved individually to $\mathbf{U}^*_{\mathbf{cp}}$, $\mathbf{U}^*_{\mathbf{cc}}$ or $\mathbf{U}^*_{\mathbf{cf}}$. In the following steps the purchases of packaging and components ($\mathbf{U}^*_{\mathbf{cp}}$ and $\mathbf{U}^*_{\mathbf{cc}}$) are allocated to the goods they are applied to. For the purchases of core materials and products to be used as final product ($\mathbf{U}^*_{\mathbf{cf}}$) no further calculation is needed. This table already represents a part of the final consumption: the direct final consumption.

2. Construction of the goods supply and use tables. The original (monetary) supply table contains information on the supply of both goods and services. The supply of services (mainly by service sectors) is not supposed to be accompanied by extensive material flows. Therefore we assume that components and packaging are used for goods, not for services. This means that, in the calculations, services do not need to be accounted for. From the original supply table $\mathbf{S}$ the rows representing products are extracted and services are left out. This results in the

goods supply table $\mathbf{S_{goods}}$. For the same reason the original (monetary) use table $\mathbf{U}$ is reduced to the goods use table $\mathbf{U_{goods}}$.

3. Construction of the percentage goods supply table. Per industry, all supplies of goods ($\mathbf{S_{goods}}$) are added, forming the total supply of goods per industry ($\mathbf{S_{goods,\ sum\ g}}$). Subsequently, per industry all supplies of goods ($\mathbf{S_{goods}}$) are divided by this total, resulting in the percentage goods supply table $\mathbf{S_{goods,\ and\ perc}}$. This table represents per industry the percentage, in monetary terms, of the supply of specific goods as part of the total supply of goods by that industry.
4. Allocation of the use of core packaging and components to the supply of goods. The percentage goods supply table $\mathbf{S_{goods,\ perc}}$ is multiplied by the purchases of core materials and products to be used as packaging $\mathbf{U^*_{cp}}$ and the purchases of core materials and products to be used as component $\mathbf{U^*_{cc}}$. This provides per industry an allocation of core packaging and components to the goods supplied by that industry. It results in two blocks of tables: $\mathbf{A^*_{cp}}$, representing the allocation of core materials and products used as packaging and $\mathbf{A^*_{cc}}$, representing the allocation of core materials and products used as component.
5. Calculation of the core packaging and components contents of goods. $\mathbf{A^*_{cp}}$ and $\mathbf{A^*_{cc}}$ show for each industry the assignment of purchased core materials and products to the commodities supplied. The sum per commodity of $\mathbf{A^*_{cp}}$ and $\mathbf{A^*_{cc}}$ represents the assignment of the total purchased core materials and products, used as packaging or as component, to each supplied commodity ($\mathbf{A^*_{cp,\ sum\ i}}$ and $\mathbf{A^*_{cc,\ sum\ i}}$; see Fig. 4). The core packaging and components contents of goods are calculated by dividing the sum per commodity of $\mathbf{A^*_{cp}}$ and $\mathbf{A^*_{cc}}$ by the total national supply of commodities $\mathbf{S_{goods,\ sum\ i}}$. Two tables result: $\mathbf{C^*_{cp}}$ showing the core materials and products contents, used as packaging, of all goods; $\mathbf{C^*_{cc}}$ showing the core materials and products contents, used as component, of all goods[8].
6. Assignment of core packaging and components to the final consumers. Purchases of goods are found in the goods use table $\mathbf{U_{goods}}$. Core materials and products, used as packaging or as component, are assigned to the final consumers by multiplying $\mathbf{U_{goods}}$ by the core materials and products contents $\mathbf{C^*_{cp}}$ and $\mathbf{C^*_{cc}}$ obtained in step (5). Value added in trade and transportation has to be taken into account.[9] The assignment results in two blocks of tables, $\mathbf{I^*_{cp}}$ and $\mathbf{I^*_{cc}}$, representing the indirect final consumption, showing which core materials and products are used, as packaging and as component respectively, connected to which goods, by which final consumers (see Fig. 4). One of the users discerned

[8] An example of what can be read from the different tables: $\mathbf{A^*_{cp}}$: x [kg] of plastic films are used by the food processing industry as packaging for potatoes. $\mathbf{A^*_{cp,\ sum\ i}}$: X [kg] of plastic films are used by the total national industry as packaging for potatoes. $\mathbf{S_{goods,\ sum\ i}}$:: the total national supply of potatoes amounts to Y [\$]. Then $\mathbf{C^*_{cp}}$: the plastic film content, used as packaging, of potatoes equals X/Y [kg/\$].

[9] Because of value added in trade and transportation, purchase prices are not equal to supply prices. Therefore core materials and products contents (expressed in [kg/\$]) are not equal for purchases and supplies. Using the value added, core materials and products contents for supplies are converted into core materials and products contents for purchases.

in the use table is 'exports'. This means that in our method exported products are ascribed core packaging and component contents too (called indirect exports). Also imported products have core packaging and components contents. 'Imports' is one of the 'suppliers' in the supply table. As a first order approach we assume that imported goods have a similar composition and are packed the same way as goods that are produced in domestic industry. Indirect imports are calculated by applying the core materials and products contents $\mathbf{C}^*_{\mathbf{cp}}$ and $\mathbf{C}^*_{\mathbf{cc}}$ to the imports figures from the supply table $\mathbf{S}$.

In order to present the results, the indirect final consumption tables $\mathbf{I}^*_{\mathbf{cp}}$ and $\mathbf{I}^*_{\mathbf{cc}}$ are summed and aggregated. Summation in the x- and y-direction leads to a pair of vectors that show the total national indirect final consumption of the core materials and products in the form of packaging and components respectively. By summation in the y- and z-direction a pair of vectors is obtained that show the indirect final consumption of core materials and products used as component and packaging, divided between the final consumers. Finally, summation in the x- and z-direction leads to a pair of vectors that show the final consumption of core materials and products used as component and packaging, divided between the goods they are applied to.

3. Discussion

In this section the reliability of the STREAMS method is discussed. In 3.1 we discuss a number of considerations about the use of supply and use tables as data sources for the analysis of material flows. In Section 3.2 we discuss the method to calculate the final consumption. In Section 3.3 the accuracy of the results is discussed and some remarks are made based on preliminary results of case studies, which are currently being conducted using the STREAMS method.

3.1. Using supply and use tables for material flows research

One of the reasons for developing the STREAMS method was to avoid the disadvantages of collecting data from different data sources—i.e. dissimilarities in definitions, in subdivisions of product groups and in reference years. Because in the STREAMS method nearly all input data are extracted from the country's supply and use tables, no dissimilarities are to be expected. However, the use of supply and use tables for the analysis of material flows involves some problems to be solved.

The lowest possible aggregation level that can be achieved in the analysis is determined by the level of aggregation of the data in the supply and use tables. The subdivision of industries and commodities that is used in the supply and use tables must also be used in the STREAMS method and affects the presentation of the results on low aggregation levels. So the possibility of deriving useful results highly depends on the aggregation level of the supply and use tables. If the aggregation level of the supply and use tables is too high, core materials and products become part of wide groups of goods, making it impossible to derive results on the core materials or products separately. Since the aggregation level of the supply and use tables differs considerably between countries, the usefulness of these tables as data sources for the analysis of material flows differs between countries as well.

In common supply and use tables, industries are discerned, not activities or processes. Most industries discerned in statistics consist of a mixture of activities, although they are categorised in statistics according to their main activity. The mixture may partly be due to the aggregation level of the statistical data: if the aggregation level is high, companies with rather different main activities are categorised in the same industry, making it impossible to determine for which activity a specific commodity is bought by a specific industry. In some countries, statistical offices recognise this problem and try to construct functional or homogeneous supply and use tables, in which activities are discerned instead of industries. For The Netherlands this has been done by Statistics Netherlands [6]. However, for most countries, these tables are not available on sufficiently low aggregation levels.

In the supply and use tables, waste figures only concern commercial waste flows that are traded. Since the greater part of the waste flows, like household waste, is not traded, it is not possible to derive data on them from the supply and use tables. For this stage of the analysis other data sources or estimates are necessary.

The conversion of monetary data into physical data is a critical step in the STREAMS method. The accuracy of the method largely depends on the way this step is conducted. Statistics Netherlands has made an effort to construct physical supply and use tables for The Netherlands for some material flows [7]. For the analysis of material flows this type of tables would be very useful. However, because a lot of work is involved in constructing these tables, it is very unlikely that they will become available for many materials and products, for many years and for many countries[10].

3.2. Calculating the final consumption

In the successive steps of the STREAMS method to calculate the final consumption of core materials and products, a number of assumptions and estimates is made that influences the accuracy of the results. The main aspects are discussed in this section.

In the first step of the final consumption analysis, an estimate is made of the purpose of use of core materials and products by industries. This estimate is mainly based on considerations about the purchasing industries and the goods they produce, combined with general knowledge on packaging methods and product compositions. More detailed studies of industries and their products are needed to achieve more accurate estimates.

The supply and use tables contain both goods and services. We assume that the supply of services is not accompanied by transfer of materials, although in practice

[10] Statistics Netherlands convert monetary supply and use tables into physical tables using specific prices for each industry, combined with balancing principles. Hekkert et al. [3] propose to include this method into the STREAMS method.

services involve relatively small transfers of, for example, spare parts and printed paper. As a result, all use of core materials and products by service industries, including trade, is regarded as final consumption.

It is impossible to assign packaging and components used in trade to the goods they are applied to, because the supply and use tables do not indicate whether goods are bought from trade or directly from the producing industry. This leads to overestimating the direct final consumption of core materials and products by trade.

In our method, packaging and components purchased by an industry are allocated to all goods supplied by that industry, on a monetary basis. In other words: the supply of each industry is assumed to consist of a range of similar goods with respect to composition, packaging method and retail price. Therefore, supply and use tables with lower aggregation levels, and consequently more homogeneous industries, lead to more accurate results. The fact that packaging and components that are purchased by an industry are allocated to all products supplied by that industry may, on a detailed level, lead to some strange results—e.g. living pigs getting a plastic package content because of use of plastic packaging in agriculture. It is possible to refine the calculation method by adding another step, not only estimating whether the purchased core materials and products are used as final product, as packaging, or as component, but also estimating which goods they are applied to[11]. However, this leads to much extra research effort as well as the need for a more detailed knowledge about the way of packing and the composition of all of the goods discerned in the use and supply tables.

Imported goods are assumed to be comparable to domestically produced goods, with regard to prices, composition and packaging method. This may cause inaccurate results for goods that are imported but not produced in the country under investigation. Because no core materials and products are used as packaging or as component for those goods in the investigated country, no core materials and products are assigned to the imported goods either. This means that the core materials and products coming along with those imported goods are neglected. Figures are more accurate for goods for which imports play a minor role. For exported goods a similar assumption is made: prices, composition and packaging method are assumed to be the same for exported goods as for goods on the domestic market.

3.3. Accuracy of the results

The STREAMS method has been tested in case studies on the plastics flows [2] and on the paper and wood flows [3] in The Netherlands for the year 1990. The most extensive supply and use tables published by Statistics Netherlands [5] contain the supply and use of 529 commodities and 114 services by 123 industries, 104 service sectors and ten final demand categories (see Fig. 2). Among the commodities that are discerned, there are 17 plastic materials and products, 37 paper materials and products and 26 wood materials and products. This suggests that the supply and use tables are reasonably detailed to be useful for the analysis of the plastics, paper and wood flows in The Netherlands.

[11] In [3] the feasibility of including this step in the STREAMS method is assessed.

The results of the analyses indicate that application of the STREAMS method provides detailed insight into the flows of the materials under investigation through the economic system of The Netherlands. Especially the indirect final consumption of materials, used as packaging or as component, can be studied in detail[12], However, it is rather difficult to compare the results of the STREAMS method to the results of other studies, because detailed studies on the final consumption of products and materials are lacking almost completely and because estimates on final consumption often use different definitions, subdivisions of product groups and reference years, whereas the reliability of these estimates is often questionable.

The input data of the STREAMS method, data from the supply and use tables, is fairly accurate. In countries like The Netherlands and Germany, these tables are constructed by the national statistical offices, based on data collected from extensive surveys. However, in the subsequent calculation steps of the STREAMS method inaccuracies are introduced. Because most of the inaccuracies concern uncertainties in modelling the real world, for which assumptions have to be made of which the extent of correctness is unknown, it is rather difficult to estimate the inaccuracy of the results.

Nevertheless, we estimate that, on disaggregated levels, the mean deviation of the results is about 30% [2]. Hekkert et al. [3] propose several improvements to the method, which reduce the mean deviation on disaggregated levels to about 15%. In general it is expected that the accuracy increases if the results are presented on a higher aggregation level. Ffor example, assigning core materials and products to individual commodities produced by an industry may lead to large inaccuracies when assessing the individual commodities. However, on a more aggregated level, the individual goods fall into a single group of commodities. This means that figures for the complete group are more accurate than figures for individual commodities.

4. Conclusions

Several countries publish annual supply and use tables to present a detailed description of their economy. As these tables show the supply and use of materials and products by industries and consumers, they contain a lot of information on the material flows through the country's economy. A condition for them being useful for the analysis of material flows is that they are sufficiently detailed. Supply and use tables differ considerably in size between countries, so their usefulness differs between countries.

In this article a new method, called the STREAMS method, is proposed to analyse material flows through society, using these national supply and use tables. Since common supply and use tables consist of monetary data, they cannot be used directly for material flows research. First they have to be converted into physical units. The applied conversion method affects the accuracy of the results.

[12] Seventeen plastic products, 37 paper products and 26 wood products assigned as packaging or component to 529 commodities, which are consumed by 228 consumers.

The STREAMS method is not limited to the direct supply and use of core materials and products. It can also be used to calculate the final core materials consumption of industrial sectors and households—i.e. the place where the core materials and products are finally consumed and turned into waste. The method to calculate the final consumption of core materials and products consists of several steps, some of which are based on assumptions on modelling material flows in society. The correctness of these assumptions, and hence the extent of congruency between the model and reality, determines the accuracy of the results of the method. There are two critical steps. Firstly, the estimate whether core materials and products are used by industries as packaging, as component or as final product. Secondly, the allocation of the packaging and components used by industries to the goods supplied by those industries. Both steps can be improved using more extensive studies, resulting in more accurate results but also leading to more research effort.

If, furthermore, data on waste release and recycling is added, the scheme of core material flows through society can be completed and the flow of core materials can be followed 'from cradle to grave'.

Case studies on the flows of plastics, paper and wood through The Netherlands have shown that the STREAMS method can serve as a powerful tool to obtain detailed knowledge about material flows through society. It provides data on the final consumption of products, which cannot be obtained from other studies and for which, up to now, only relatively rough estimates were available. Although comparison of the results of the STREAMS method to results of other studies is very difficult and often impossible, the case study on plastic flows in The Netherlands suggests that the results are, at least on aggregated levels, reasonably accurate. The case study on paper and wood flows in The Netherlands shows that the accuracy of the results can be further increased by including a number of improvements to the calculation method. In order to test the wider applicability of the method, further research should aim at applying it to the analyses of different material flows through different countries for which supply and use tables are available.

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